Cardiopulmonary Exercise Testing– Clinical Implications

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Outline

• Basic concepts
• Case studies
• Recent advances in clinical applications of CPET
Basic Concepts
Exercise

• Any physical activity in which work is performed by skeletal muscle can be regarded as exercise

• 2 types
  – Resistance exercise (brief periods of muscle contraction at high forces) eg weightlifting
  – Endurance/aerobic exercises (lower intensity contractions performed rhythmically for extended periods of time) eg. Walking, running and cycling
Cardiopulmonary exercise testing (CPET)

• Relatively noninvasive, dynamic physiologic test that permits the evaluation of both submaximal and peak exercise responses

• Provides a global assessment of the integrative exercise responses involving the pulmonary, cardiovascular, hematopoietic, neuropsychological, and skeletal muscle systems, which are not adequately reflected through the measurement of individual organ system function

• Provides the physician with relevant information for clinical decision making
Indications

• Evaluation of exercise tolerance
  – Determination of functional impairment or capacity (peak $V\dot{O}_2$)
  – Determination of exercise-limiting factors and pathophysiologic mechanisms

• Evaluation of undiagnosed exercise intolerance
  – Assessing contribution of cardiac and pulmonary etiology in coexisting disease
  – Symptoms disproportionate to resting pulmonary and cardiac tests
  – Unexplained dyspnea when initial cardiopulmonary testing is nondiagnostic
Indications

• Evaluation of patients with cardiovascular disease
  – Functional evaluation and prognosis in patients with heart failure
  – Selection for cardiac transplantation
  – Exercise prescription and monitoring response to exercise training for cardiac rehabilitation (special circumstances; i.e., pacemakers)
Indications-Evaluation of patients with respiratory disease

• Chronic obstructive pulmonary disease
  – Establishing exercise limitation(s)
  – Assessing other potential contributing factors, especially occult heart disease (ischemia)
  – Determination of magnitude of hypoxemia and for O2 prescription
  – Objective determination of therapeutic intervention

• Interstitial lung diseases
  – Detection of early (occult) gas exchange abnormalities
  – Determination of potential exercise-limiting factors
  – Documentation of therapeutic response to potentially toxic therapy
Indications

- Pulmonary vascular disease (careful risk–benefit analysis required)
- Cystic fibrosis
- Exercise-induced bronchospasm
Specific clinical applications

• Preoperative evaluation
  – Lung resectional surgery
  – Elderly patients undergoing major abdominal surgery
  – Lung volume reduction surgery for emphysema

• Exercise evaluation and prescription for pulmonary rehabilitation

• Evaluation for impairment–disability

• Evaluation for lung, heart–lung transplantation
Contraindications

- Acute MI (in first week)
- Active endocarditis/pericarditis/myocarditis
- LMCA stenosis
- High degree heart block
- Pulmonary edema
- Respiratory failure
- Significant pulmonary hypertension
Indications for Exercise Termination

• Chest pain
• Ischemic ECG changes
• Heart block
• HTN SBP > 250 or DBP >120
• SpO2 < 80%
• Sudden pallor
• Faintness
• Respiratory failure
Equipment

- Exercise equipment
- Airflow or volume transducers
- Gas analysers
- Electrocardiograph
- NIBP
- Pulse oximetry
- Intraarterial BP monitoring and ABG (invasive, optional, SOS)
How we do it?
Exercise Protocol

• Maximal incremental cycle ergometry protocol
• Maximal incremental treadmill protocol
• Constant work rate protocol
# Measurements during CPET

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<th>Measurements</th>
<th>Noninvasive</th>
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Variables Used for Interpreting Results
$V_{O_2} \text{ max}$ and Peak $V_{O_2}$

- **$V_{O_2} \text{ max}$**
  - Represents maximal achievable oxidative metabolism using large muscle groups
  - Clear plateau achieved during exercise
  - Gold standard for cardiopulmonary fitness

- **Peak $V_{O_2}$**
  - $V_{O_2}$ at maximal exercise without a plateau
  - Used interchangably with $V_{O_2} \text{ max}$
$V_{O2\ max}$

- Low $V_{O2\ max}$: Starting point in evaluation of reduced exercise tolerance
- Normal values
  - Men: $[\text{Ht (cm)} – \text{Age (yr)}] \times 21$
  - Women: $[\text{Ht (cm)} – \text{Age (yr)}] \times 14$
  - LLN: 83% of predicted
- Decreased in:
  - CHF, COAD, IPF, Pulmonary vascular disease (PVD), deconditioning, anemia
**V\textsubscript{O2}-Work Rate Relationship**

- \(\Delta V\textsubscript{O2}/\Delta WR\) - Slope represents the efficiency of the metabolic conversion of chemical potential energy to mechanical work
- Independent of age, sex and height
- \(V\textsubscript{O2}\) for a given WR is higher in obese but slope is normal
- Normal value: 10.0 ml/min/watt (LLN: 8.5)
- High in: obesity, hyperthyroidism, poor exercise technique
Respiratory Exchange Ratio (RER)

• Ratio of $V_{CO2}/V_{O2}$
• Under steady state: equals RQ (cellular level)
• At rest, $< 1.0$, near to 0.8 (mixed metab of carbohydrates, fats and proteins)
• During exercise, equals 1 (glycogen primarily metabolised)
• Exceeds 1, when anaerobic threshold is reached
Anaerobic Threshold (AT)

- Term *introduced by* Wasserman and McIlroy in 1964\(^1\)
- Critical or threshold level of work above which exercise is associated with a systemic lactic acidosis, indicative of nonoxidative glycolysis
- Normal value: 50-60% of \(V_{O2\text{max}}\) (LLN: 40%)
- Marker of exercise that cannot be sustained for very long

Anaerobic Threshold

- Non specific marker like $V_{O2} \text{ max}$
- Decreased in:
  - Heart failure
  - Pulmonary vascular disease
- Can be decreased or normal in:
  - COAD
  - ILD
  - Deconditioning
Determination

• Invasive
  – Arterial lactate: by ABG every 2 min
  – Arterial bicarbonate: if lactate NA

• Noninvasive
  – Modified V-slope method -- Point of change in slope of relationship of $V_{CO2}$ versus $V_{O2}$ ($V_{O2}$ above which $V_{CO2}$ increases faster than $V_{O2}$ without hyperventilation)
Heart rate

- Maximal predicted heart rate: 210 – (age X 0.65)
  - LLN: > 90% of predicted
- Heart rate reserve (HRR): Difference between age predicted maximal HR and actual heart rate achieved during exercise
- Normal: < 15 beats/min
- Maximal heart rate response decreased in multiple cardiorespiratory diseases
Blood Pressure Response

• Systolic BP progressively with increasing $V_{O2}$
• Diastolic BP remains constant or may decline slightly
• Abnormal responses: excessive rise, reduced rise or a fall
• Higher limit of normal: < 220/90
Oxygen Pulse

- Ratio of $V_{O2}$ to HR
- Fick’s equation: $CO = SV \times HR = VO2/ C \ (a-v) \ O2$
- On rearranging:
  $VO2/HR \ (oxygen \ pulse) = SV \times C \ (a-v) \ O2$
- Increases with incremental exercise, till it flattens at maximal work rate
- Low flat oxygen pulse represents low stroke volume: heart failure, pulmonary vascular disease, deconditioning
Ventilation

- During exercise: both Vt and fR increase till 70-80% of peak exercise thereafter, fR predominates
- Vt plateaus at 50-60% of VC
- Ventilatory demand: Ve at a given level of exercise
- Increased in: COAD, ILD, PVD (due to increased dead space ventilation, V-Q mismatch, stimulation of lung receptors)
Ventilation

• Ventilatory capacity: maximal minute ventilation (MVV), best measure of ventilatory capacity till date
  
  • MVV = FEV1 X 35-40

• Ventilatory Reserve: Reciprocal of
  
  – Ve peak/ MVV X 100
  – Normal: < 85% (72 ± 15%)

• Or alternatively, MVV – Ve peak (>11 L)
Ventilatory Reserve

• Good discriminatory value
• Ve peak/MVV high in COAD (reaches 100% or higher)
• High in ILD, but lower than COAD
• Normal or decreased in heart failure
$V_E - V_{CO2}$ Relationship

- $V_E/V_{CO2}$: Represents ventilatory response in relation to rise in CO2 production
- Normal: $< 34$ (L/L) at AT
- Increased in COAD, ILD, heart failure, PVD
- Discriminates cardiopulmonary disorders from obesity and deconditioning
**$V_E - V_{CO2}$ Relationship**

- Rise in $V_E/V_{CO2}$ low if insensitivity to high PaCO2 and ventilatory restriction as in some COAD patients
- $V_E/V_{CO2}$ high (with low $P_{ET}$ CO2): hyperventilation (psychogenic: HVS/ anxiety)
Pulmonary Gas Exchange

• Significant hypoxemia:
  – SpO2 ≤ 88% or
  – PaO2 ≤ 55mmHg or
  – ΔSpO2 ≥ 4%

• Differentiates between predominantly cardiac and pulmonary cause

• More in ILD, PVD than in COAD

• P (A-a) O2: Increased in ILD, PVD and some COAD (Normal: <35)
Dead Space

- Physiologic dead space to tidal volume (Vd/Vt)
- $\frac{Vd}{Vt} = \frac{PaCO2 - PE CO2}{PaCO2}$
- $PE CO2 =$ mixed expired value of alveolar and dead space gas
- Normal: 0.28
- Increased in COAD, ILD, heart failure, PVD
- Discriminates cardiopulmonary disease from deconditioning and obesity associated limitation
Perceptual Assessment -- Symptoms

• Grading of dyspnea and leg muscle fatigue
  – VAS: 0 to 100 or
  – Borg’s category ratio (CR-10) scale: 0 to 10 (open ended) along with verbal descriptors of severity

• Usually recorded at peak exercise

• Can be recorded at multiple time points during exercise

• Ratings of dyspnea and fatigue are reduced after pulmonary rehabilitation
Recent Advances in Clinical Applications of CPET
Evaluation of Exercise Capacity after Lung Transplantation
Lung Transplantation

• Bartels MN\(^1\)
• 153 patients transplanted over 7 years who had complete cardiopulmonary exercise testing (CPET) and pulmonary function tests (PFT) pre- and post- lung transplantation
• Pulmonary function markedly improved post-transplant as forced vital capacity increased 67%, maximum voluntary ventilation increased 91% and forced expired volume in 1 second increased 136%.

\(^1\) Chest 2011 Jun 16. [Epub ahead of print]
Bartels et al

- VO2 max increased only 19%, peak carbon dioxide production increased 50% and peak work increased 78%
- Although 1.5 to 2.0-fold increase in exercise capacity post-transplant, peak exercise capacity remained at 50% of the predicted normal, suggesting a maximal limitation
- Indicates poor strength, deconditioning or other peripheral factors play a significant role in the limitation of exercise benefit post-transplantation
Prognostication of Patients with ILD
Idiopathic Pulmonary Fibrosis

• Fell CD et al\(^1\)
• 117 patients with IPF and longitudinal cardiopulmonary exercise tests were examined retrospectively
• Baseline maximal oxygen uptake less than 8.3 ml/kg/min had an increased risk of death (n = 8; hazard ratio, 3.24; 95% confidence interval, 1.10-9.56; P = 0.03) after adjusting for age, gender, smoking status, baseline forced vital capacity, and baseline diffusion capacity for carbon monoxide

\(^1\) Am J Respir Crit Care Med. 2009 Mar 1;179(5):402-7
Evaluation of PR in COAD
Lan CC et al

- Twenty-two underweight COPD patients who participated in 12-week, hospital-based outpatient PRP consisting of two sessions per week. Baseline and post-PRP status were evaluated by spirometry, cardiopulmonary exercise testing, ventilatory muscle strength and the St. George's Respiratory Questionnaire (SGRQ)
- Significant improvements in peak oxygen uptake, peak workload and the SGRQ total, symptoms, activity and impact scores in both underweight and non-underweight patients with COPD (all P < 0.05)

¹Respirology 2011 Feb;16(2):276-83
Summary

• CPET is a dynamic physiologic test that permits the evaluation of both submaximal and peak exercise responses

• Major indications include evaluation of exercise intolerance in undiagnosed as well as known patients of cardiorespiratory diseases

• $V_\text{O}_2\text{ max}$ and anaerobic threshold are two most important measures of exercise capacity
• CPET helps to differentiate cardiopulmonary causes of exercise limitation from peripheral and neuropsychological causes.

• Helps to discriminate between cardiac and pulmonary contribution to a patient’s exercise intolerance.